A Unified Numerical Model for Simulating Complex Flow, Chemical Transport, and Heat Transfer in Petroleum Reservoirs

Yu-Shu Wu
Earth Sciences Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720, USA

Abstract

Despite advances made in reservoir simulation over the past few decades, the need to simulate increasingly complex reservoir processes, such as multiphase fluid displacement, coupled with chemical reactions, in enhanced oil recovery, forces modelers to continually seek for new or improved mathematical models and numerical techniques. It has long been recognized, however, that a common ground exists between governing equations used for describing various flow and transport phenomena in reservoirs–i.e., these physical processes are all governed by the same form or analogy of mass and energy conservation laws. This suggests that it may be possible to develop a unified formulation and numerical scheme applicable to modeling all of these physical processes. This paper explores such a possibility and proposes a generalized framework formulation for modeling all known flow and transport phenomena in porous media. A unified numerical approach is then developed for modeling multidimensional, isothermal and nonisothermal multiphase flow and chemical transport in porous and fractured reservoirs. In this generalized approach, a spatial discretization is performed using an unstructured grid with control-volume or integral finite difference scheme, and the time is discretized with a backward, first-order, finite-difference method. In addition, a generalized wellflow model using a virtual node approach is implemented for handling various production and injection wells, including vertical, horizontal and inclined wells. The final discrete nonlinear equations are handled fully implicitly or adaptively implicitly and solved using the Newton iteration.

As demonstrated in this work, this unified approach makes practical reservoir simulation simply a matter of defining a set of state variables, along with describing their interrelations (or mutual influence) and specifying boundary and initial conditions. In addition, the unified model formulation can be incorporated into both single-CPU and parallel-computing simulators. As application examples, the unified numerical method has been tested in two three-dimensional, multiphase reservoir simulators for modeling multiphase flow, water shut-off operation, and heat transfer in porous and fractured reservoirs. The proposed modeling approach is shown to be able to simulate all the known flow and transport processes in reservoirs, including Newtonian, non-Newtonian, or non-Darcy flow of oil, water and gas, coupled with advective, diffusive and adsorptive transport of chemicals under chemical flooding or thermal recovery operations.

In particular, commonly used non-Newtonian rheological models are incorporated for modeling single-phase and multiphase non-Newtonian flow, while the non-Darcy flow is generally described by the *Forchheimer* equation. The fractured reservoir is handled using a general dual-continuum concept with continuum or discrete modeling approaches.